



LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-TR-426090

X-ray source brightness comparison: Rigaku rotating anode source vs. Kevex microfocus tube

J. A. Koch, E. Dewald, B. Kozioziemski

March 18, 2010

Disclaimer

This document was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor Lawrence Livermore National Security, LLC, nor any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or Lawrence Livermore National Security, LLC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or Lawrence Livermore National Security, LLC, and shall not be used for advertising or product endorsement purposes.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

X-ray source brightness comparison: Rigaku rotating anode source vs. Kevex microfocus tube

Jeffrey A. Koch, Eduard Dewald, Bernie Kozioziemski

I. Introduction

In 2007, we began to explore alternative x-ray sources for application to refraction-enhanced (phase contrast) x-ray radiography of cryogenic NIF ignition capsules containing frozen deuterium-tritium (D-T) ice layers [1]. These radiographs are currently obtained using Kevex microfocus tubes [2] as backlights, and for these sources the x-ray source size is approximately 5 μm . As part of this exploration, we obtained refraction-enhanced radiographs of empty plastic capsules using the Janus laser facility at LLNL, demonstrating that even large ($\sim 100 \mu\text{m}$) sources can be utilized in refraction-enhanced radiography provided the source/sample distance is sufficiently large, and provided the final x-ray detector has sufficient spatial resolution [3, 4]. Essentially, in the current geometry, we rely on a small source to provide spatial resolution and on the source/sample distance to provide refraction contrast, but an equally useful alternative geometry is to use a large source and rely on fine detector spatial resolution to provide spatial resolution and on the sample/detector distance to provide refraction contrast.

Refraction-enhanced radiography is particularly important for quantifying the dimensions of grain-boundary grooves that are often present in the ice layers [5]. For a groove of depth A , width w , radiographed with a source/object distance of p and an object/detector distance of q and a source wavelength λ , the following inequality must hold if the groove is to be detected:

$$\text{Contrast} \propto \frac{A\lambda^2}{w^2} \frac{pq}{(p+q)} > \frac{1}{S/N} \approx \frac{1}{\sqrt{N}} \quad (1)$$

where S/N is the signal-to-noise ratio and N is the detected number of photons per resolution element. Typically, w is roughly constant [5], and grooves have variable depths. We can write the number of photons per resolution element as:

$$N \propto I\sigma^4 \frac{(p+q)^2}{p^2q^2} \quad (2)$$

where σ is the spatial resolution and I is the source intensity is photon per unit area. Combining (1) and (2), we see that in order to detect a groove with minimum depth A_{minimum} , the following scaling holds:

$$A_{\min imum} \propto \frac{w^2}{\lambda^2 \sigma^2 \sqrt{I\tau}} \quad (3)$$

We see that the minimum detectable groove depth scales with w , which is roughly constant for all grooves; with $1/\lambda^2$; with $1/\sigma^2$, which is not a free parameter because we require spatial resolution at the sample of $\sim 5 \mu\text{m}$; and with $1/\sqrt{I\tau}$, where τ is the integration time. Therefore, the path to improved radiography images moves to longer wavelengths, brighter sources, and longer integration times, regardless of the size of the source.

We recently tested a powerful rotating anode source, a Rigaku 007HF [6], for source brightness in experiments at Rigaku's Houston facility, and compared the results to what we obtain from our current Kevex sources. The Rigaku source has promise to improve the quality of our refraction-enhanced radiographs, by having high brightness and longer wavelengths despite having a relatively large source diameter. We find a net improvement of a factor of 3.2 in the metric $\lambda^2\sqrt{I}$, equivalent to taking exposures with the Kevex source that are 10.4 times longer than current exposure times of ~ 300 seconds. Equivalently, with a fixed exposure time of 300 seconds, the Rigaku source would allow grooves that are 0.31 times as deep to be detected with the same fidelity.

II. Rigaku Tests

In September 2009, we arranged a demonstration test of the Rigaku 007HF at Rigaku's Houston facility, using their source and an Xradia detector [7] that we shipped to Houston from LLNL. This detector had been pre-calibrated at NSTec's Livermore facility for optical CCD counts per incident photon, and the results are summarized in Table 1 below.

Anode, filter	Energy, eV	Counts per photon
Ag, no filter	2120	0.78
Ti, no filter	4510	2.08
Ti, Ti 25 micron	4620	2.18
Cr, Cr 25 micron	5700	3.17
Fe, Fe 25 micron	6650	4.01
Cu, Ni 25 micron	8470	8.2

Table 1: NSTec calibration results for the Xradia detector.

The source ran a Cr anode, emitting principally 5.4 keV radiation. Operating power was 870 Watts, and the source/detector distance was 2372 mm. 275 mm of this distance was through an air path, and the total filtration was 17.874 mils Be and 2 mils kapton ($C_{22}H_{10}N_2O_5$, 1.43 g/cm³). The source size is 70 μ m. A schematic of the test geometry is shown in Figure 1 below.

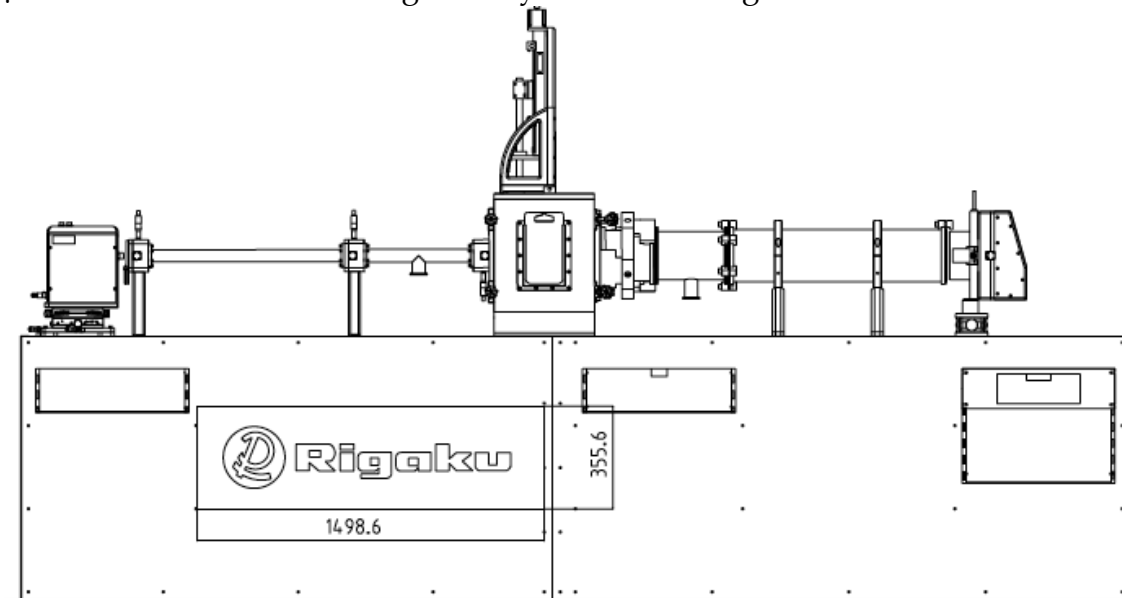


Figure 1: Test geometry at Rigaku. The x-ray source is on the far left emitting x-rays through a collimating hole, and the x-ray detector is on the far right.

After turning on the source, we acquired exposures for fixed lengths of time, and then acquired background exposures with the source off for the same fixed lengths of time. Subtracting the background exposure provides a map of quasi-uniform counts that can be related to the photon flux through Table 1.

III. Kevex Tests

We performed essentially identical tests with the Kevex source in the B298 cryogenic target laboratory, which primarily emits 8.5 keV radiation. The source ran a Ta anode, principally emitting 8.5 keV radiation. The source/detector distance was 810 mm, and this path was entirely in air. Total filtration was 4.9 mils of Be, and the source size was 5 μ m. We again acquired both exposures and background images, and subtracting the background exposure provides a map of quasi-uniform counts that can be related to the 8.5 keV photon flux through Table 1.

IV. Results

The tabulated results are show in Table 2 below.

	Rigaku 100-sec image	Kevex 1000 sec image
Peak exposure (counts)	589.0000	746.0000

Energy (keV)	5.4000	8.5000
NSTEC		
counts/photon with filters	3.1700	8.2000
Distance (cm)	237.2000	81.0000
Exposure time (s)	100.0000	1000.0000
Air path (cm)	27.5000	81.0000
Air attenuation	0.2943	0.3739
Be thickness (mils)	17.8740	4.9210
Be attenuation	0.7598	0.9794
kapton thickness (mils)	2.0000	0.0000
kapton attenuation	0.8675	1.0000
Pixel size (cm) (approximate)	0.0001	0.0001
Source brightness (photons/s/Sr)	2.1560E+14	6.5206E+11
Ratio (Rigaku/Kevex)	330.6494	1.0000
Source size (μm)	70.0000	5.0000
Net improvment in photons/s/Sr/ μm^2	1.6870	1.0000
Net improvement in contrast metric, including wavelength ²	3.2181	1.0000

Table 2: Summary of test results

We find an overall improvement of a factor of 3.2 in the contrast metric $\lambda^2 \sqrt{I}$, equivalent to taking exposures with the Kevex source that are 10.4 times longer than current exposure times of ~ 300 seconds. Equivalently, with a fixed exposure time of 300 seconds, the Rigaku source would allow grooves that are 0.31 times as deep to be detected with the same fidelity. We note that for the comparison to hold, the final detector for the Rigaku source geometry must be capable of resolving $4.5 \mu\text{m}$ features in the object including source broadening, since this is the object resolution with the current Kevex source geometry. Finally, we note that eq. (3) is a ray-based approximation, and full diffraction calculations should be performed before any decisions are made about what sources we should use for future D-T radiography.

We thank Chuck Dunham, Adam Courville, Joe Ferrara, and everyone else at Rigaku for arranging the test demonstrations and for their hospitality during our visit, and we thank Mike Haugh at NSTec for performing the detector calibrations. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.

References

- [1] Jeffrey A. Koch, Eduard Dewald, Nobuhiko Izumi, Bernie Kozioziemski, Otto Landen, Craig Siders, "Pulsed laser-based x-ray sources for rapid-cool DT layer characterization", Internal Memo UCRL-TR-234487 (2007).
- [2] Thermo Scientific model PXS927EA-LV, <http://www.thermo.com/>.
- [3] N. Izumi, E. Dewald, B. Kozioziemski, O. L. Landen, J. A. Koch, "Development of a laser-produced plasma x-ray source for phase-contrast radiography of D-T ice layers", *Fusion Science and Technology* 55, 253 (2009).
- [4] Jeffrey A. Koch, Otto L. Landen, Bernard J. Kozioziemski, Nobuhiko Izumi, Eduard L. Dewald, Jay D. Salmonson, Bruce A. Hammel, "Refraction-enhanced x-ray radiography for inertial confinement fusion and laser-produced plasma applications", *Journal of Applied Physics* 105, 113112 (2009).
- [5] A. Chernov, B. J. Kozioziemski, J. A. Koch, L. J. Anderson, M. A. Johnson, A. V. Hamza, S. O. Kucheyev, J. B. Lugten, E. A. Mapoles, J. D. Moody, J. D. Salmonson, J. D. Sater, *Applied Physics Letters* 94, 064105 (2009)
- [6] <http://www.rigaku.com/>
- [7] <http://xradia.com/>